

WorldSpace Radio

the first worldwide satellite radio

by G. Kleine

The new digital WorldSpace satellite radio broadcast service covers a large fraction of the earth's surface using three geostationary satellites. Over four billion people — 80% of the world's population — can receive WorldSpace.



[illustration reproduced courtesy of HIT MIX FMM AG, Unterföhring]

WorldSpace is chiefly aimed at the inhabitants of Africa, the Near East, Asia and Latin America, since these are regions which are not well supplied with radio stations. However, thanks to the rapid advance of satellite technology, the WorldSpace programmes are now available elsewhere as well. Indeed, the West beam of the AfriStar satellite, aimed at Africa, can be received in Europe as far north as Scandinavia and Scotland. In this article we will describe the communications technology behind WorldSpace and the receivers, which are now becoming available.

The WorldSpace satellite radio system arose from the idea of providing a wide range of radio programmes to areas of the developing world not well supplied with radio sta-

tions, but without the expense of building a terrestrial transmitter network. The WorldSpace company itself was founded in 1990 by the Ethiopian Noah A. Samara (now 42 years old) and is based in Washington, USA. There are three satellites, AfriStar, AsiaStar and AmeriStar, which send out a wide selection of radio programmes. Each of the three satellites has three partially overlapping footprints, the so-called 'beams' (Figure 1). There is a West beam, an East beam, and a South beam.

The satellites are geostationary and are monitored and controlled from control centres on each conti-

nent. They were built by Alcatel Space of Toulouse and Matra Marconi Space in France. AfriStar and AsiaStar have already been launched on Ariane rockets from Kourou in French Guyana. AmeriStar will follow this year.

Some well-known electronics companies are also involved with WorldSpace radio: Micronas Intermetall are producing the Starman chipset for the WorldSpace receiver and Rohde & Schwarz produces the signal generators used in the development and production of the receivers.

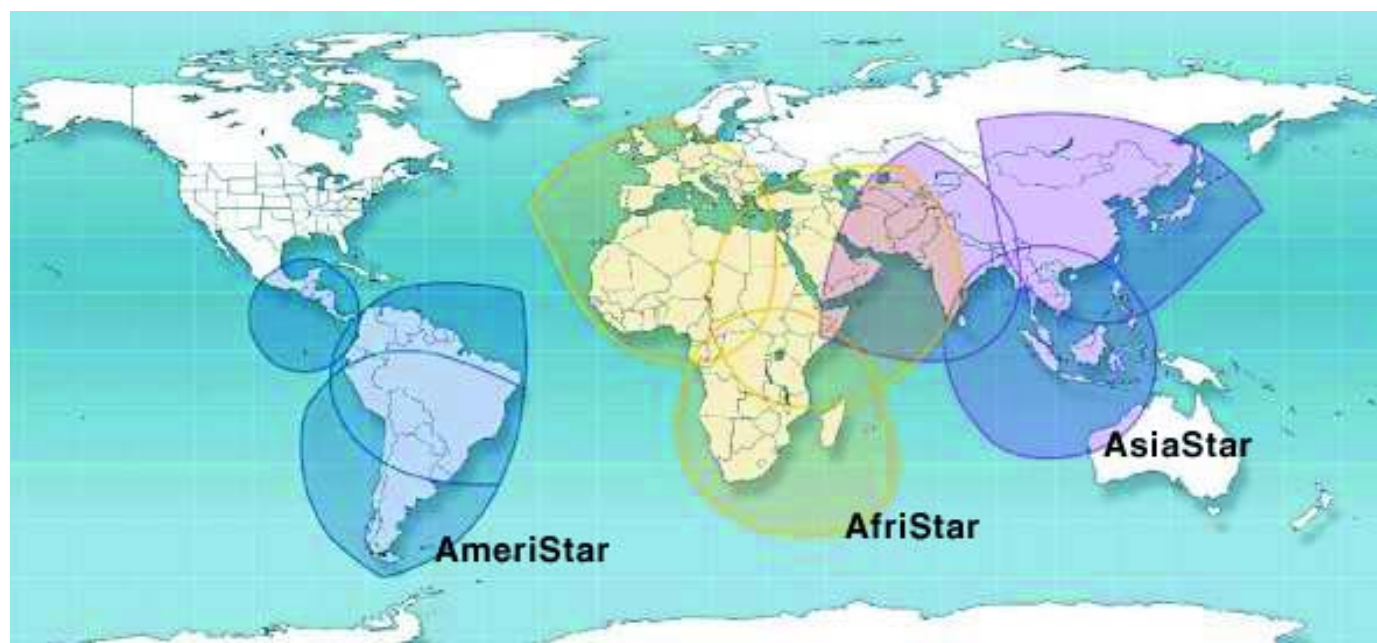


Figure 1. Coverage of the three WorldSpace satellites (illustration reproduced courtesy of Worldspace Germany).

Flexible channels

In each beam two signals are transmitted, each carrying 96 basic channels (so-called Prime Rate Channels, or PRCs), each of which runs at 16 kbit/s in time division multiplex (TDM), providing a total of up to 576 ($= 2 \times 3 \times 96$) basic channels per WorldSpace satellite. The digital communication employs compression according to the MPEG layer 3 protocol (also known as MP3). According to the sound quality required a radio station can occupy from one half of a basic channel (8 kbit/s, mono at AM radio quality) to as many as eight

basic channels (128 kbit/s, stereo at CD quality): see **Table 2**.

The allocation of the basic channels leased by a programme provider can be changed from time to time, so that for example a news broadcast in six languages at mono quality can share capacity with a hi-fi broadcast at 96 kbit/s ($6 \times 16 \text{ kbit/s} = 96 \text{ kbit/s}$). The selection is made via the Service Components of the signal, described later. The programme provider can also allocate a fraction of the basic channels to data, to provide accompanying textual information in a similar fashion to Teletext. Channel selection is also simplified

for the user by the use of this side data channel (station name, language and programme type — see **Table 3**).

Further, a programme provider can transmit in encrypted form using so-called 'Pay Audio'. The listener is provided with a code number which must be entered into the receiver in order to receive the channel.

In order to avoid the need to bring all the channels together at a single satellite uplink station, WorldSpace provides for a TDM data stream (one per beam) whereby each programme provider has their own SCPC (single channel per carrier) uplink, in addition to a TDM channel per beam from a central uplink station. Using the 7 GHz band, the various WorldSpace customers transmit their com-

Table 1. Summary of WorldSpace satellites

Satellite	AmeriStar	AfriStar	AsiaStar
Position	95° West	21° East	105° East
Target region	South America, Caribbean region	Africa, Near East, Middle East, Central and Southern Europe	China, India, Indonesia, the Philippines, Thailand, Japan
Uplink	7.025 to 7.075 GHz (X-band)		
Downlink	1.452 to 1.492 GHz (L-band)		
Transmit power per beam	2x 150 W (TWTA)		
Launch date	2002 (planned)	28 October 1998	21 March 2000
First operation	2002 (planned)	19 October 1999	10 June 2000
Operating centre	Trinidad and Tobago	Washington, D.C.	Melbourne
TCR stations	Santiago, Chile Washington, D.C. Trinidad & Tobago	Libreville, Gabon Bangalore, India Port Louis, Mauritius	Melbourne Bangkok, Thailand Port Louis, Mauritius

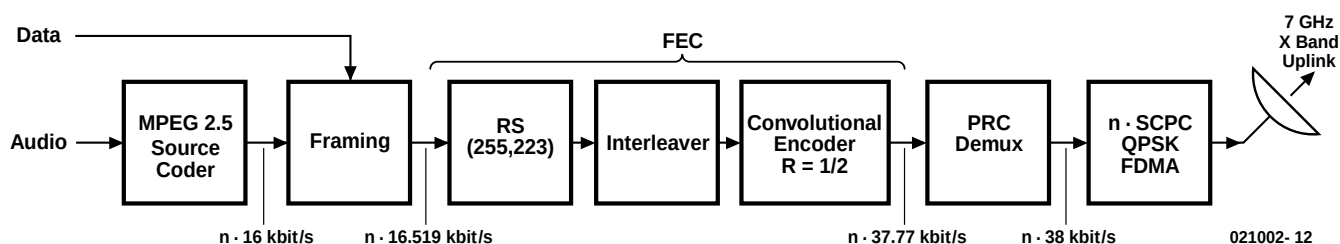


Figure 2. Block diagram of a WorldSpace SCPC uplink station.

Table 2. Data rates and quality levels

n = number of basic channels	data rate	audio bandwidth	quality	maximum number of programmes per satellite
1	16 kbit/s	4.5 kHz	AM radio	288
2	32 kbit/s	7.5 kHz	FM radio, mono	144
4	64 kbit/s	11 kHz	FM stereo	72
6 to 8	96 to 128 kbit/s	> 15 kHz	CD quality	36 to 48

pressed data streams to the satellites where they are received, demodulated and coded into a WorldSpace standard signal along with data streams from other programme providers. The result is a separate data stream for each beam. The carrier of each TDM signal is modulated using QPSK and has a total bit rate of 3.68 Mbit/s. Because bits are encoded in pairs into the phase of the carrier, we can quote a symbol rate of 1.84 Msymbol/s.

Each of the three beams of the satellite carries two TDM signals: one with 96 basic channels, which is constructed from the SCPC uplinks, and another, which comes from the central uplink and which in the satellite undergoes only a change in frequency, without being demodulated or decoded: the transponder is essentially transparent. This second signal also contains 96 basic channels. Each beam therefore has 192 basic channels available. In order to make more efficient use of the frequency band, circular polarisation is used; this is also ideal for use with flat (or 'patch') antennas at the receiver. Each beam thus includes a right-hand circularly polarised and a left-hand circularly polarised TDM QPSK signal, whose spectra can overlap. **Table 4** gives more information on the carrier frequencies of the TDM signals.

Uplink

The uplink system starts with an MPEG 2.5 encoder, as shown in **Figure 2**. Depending on the quality required, this produces a data stream at a rate of n times 16 kbit/s. Next there is a framing stage which organises the

Table 3. Languages and programme types

Languages	Programme types
English	News
Spanish	Information
Arabic	Sport
Portuguese	Education
French	Children
German	Talk
Mandarin	Word Entertainment
Hindi	European Classical
Bahasa	Soundtrack
Tagalog	Jazz
Swahili	Country
Hausa	Pop Music
Urdu	Urban
Korean	other
Thai	
other	

Abbreviations:

BC	Broadcast Channel
C/N	Carrier / Noise
FDMA	Frequency Division Multiplexing Access
FEC	Forward Error Correction MFP
	Master Frame Preamble
MPEG	Motion Picture Experts Group
PRC	Prime Rate Channel
QPSK	Quaternary Phase Shift Keying
RS	Reed-Solomon
SC	Service Component
SCPC	Single Channel per Carrier
TCR	Telemetry, Command & Ranging
TDM	Time Division Multiplex
TDMA	Time Division Multiplexing Access
TSCC	Time Slot Control Channel
TWTA	Travelling Wave Tube Amplifier

Table 4. Transponders on AfriStar

Beam	Transponder*	Frequency
East beam	34R	1468.564 MHz
East beam	39L	1470.864 MHz
South beam	44L	1473.164 MHz
South beam	49R	1475.464 MHz
West beam	55R	1478.224 MHz
West beam	60L	1480.524 MHz

*nnR = right-hand circularly polarised, nnL = left-hand circularly polarised

data into a framed format, along with the side channel data. Now at a rate of n times 16.519 kbit/s, the data undergo FEC (forward error correction) coding, consisting of a Reed-Solomon encoder, an interleaver and a convolutional encoder.

The Reed-Solomon encoder uses a block code, where 32 extra parity bytes are added to each 223-byte block. The parity bytes are calculated from the data using a complex algorithm which allows the receiver to correct as many bit errors as possible. Because the Reed-Solomon stage converts 223 bytes into 255 bytes, it can be referred to as an RS (255,223) encoder. With 32 parity bytes up to 16 erroneous bytes in each 223 byte block can be corrected. If there are more errors than this, then it is only possible to detect the errors, not correct them.

The interleaver which follows reorders the bytes in time according to a fixed pattern. This means that, if a long burst of errors occurs in transmission, when the bytes are reassembled into the correct order by the deinterleaver in the receiver the erroneous ones will be spread out, and it will then be possible to correct the individual errors.

The final part of the forward error correction coding is the convolutional encoder. This consists of a 7-bit shift register, whose outputs produce two new data streams, each at the original data rate, according to a fixed formula given by two so-called generator polynomials $G_x = 171_{oct}$

$= 1111001_{bin}$ and $G_y = 133_{oct} = 1011011_{bin}$. This is therefore a 'rate 1/2 code': the output data rate is twice that of the incoming data. The convolutional encoder further improves the overall robustness of the communications system to external interference.

The Prime Rate Channel demultiplexer constructs individual 38 kHz channels from the FEC-protected data stream, and they are finally transmitted to the WorldSpace satellites as a bundle of QPSK-modulated signals in frequency-division multiplex (FDMA, or Frequency Division Multiple Access: see **Figure 3**) using carriers in the X-band (7.025 to 7.075 GHz). The SCPC uplink station must of course lie within the footprint of the satellite's receiving antenna. Transmit powers of between 10 W and 100 W are used, with an antenna diameter of two to three metres.

Satellite

The FDMA signal is received in the WorldSpace satellite (**Figure 4**) and QPSK-demodulated. A demultiplexer separates it into the individual 38 kHz signals so that all the PRC channels from all the programme providers are available at the multiplexer that follows. This allows each individual data stream to be switched to one or more of the three channels on the three beams of the satellite. The next block performs rate alignment, where the data rates

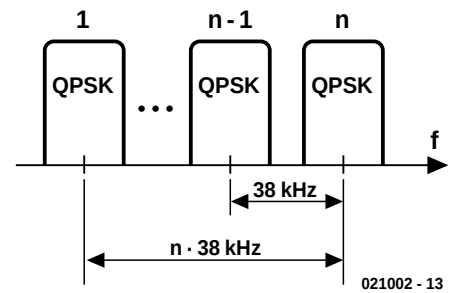


Figure 3. FDMA spectrum from a WorldSpace SCPC uplink station.

of each beam are adjusted to a nominal value. The following TDMA (Time Division Multiple Access) multiplexer organises the data streams for each beam into a single stream which contains all the channels in a time-multiplexed arrangement. In order to make the master frame identifiable a Master Frame Preamble (MFP) is added. Information is also required as to which Prime Rate Channels are associated with which programme channel, or so-called Broadcast Channel (BC). This is held in the Time Slot Control Channel (TSCC) in the data stream, which contains the allocation of the PRCs that follow it.

The overall data stream so produced can now be fed to the QPSK modulator and the satellite's power output stage. This can deliver about 300 W of RF power per beam. The antenna then beams the WorldSpace signal in the L-band (1.452 to 1.492 GHz), with either left-hand or right-hand circular polarisation, back down to earth.

The programme providers can divide their available PRCs (up to eight) into so-called Service Components (SCs). For example, 8 PRCs can be divided into a stereo audio channel

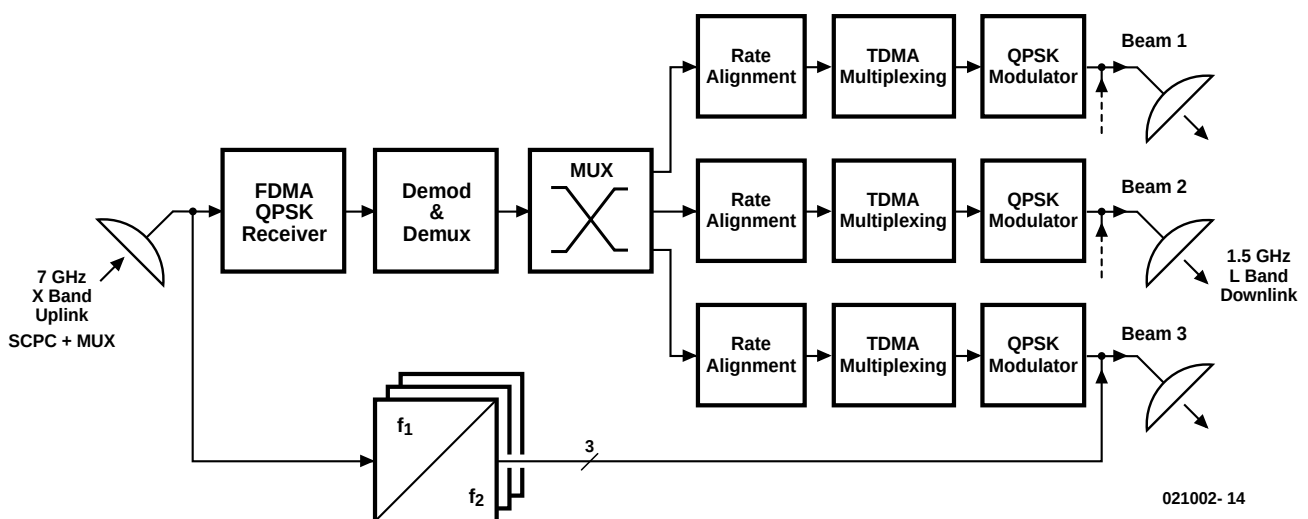


Figure 4. Block diagram of a WorldSpace satellite.

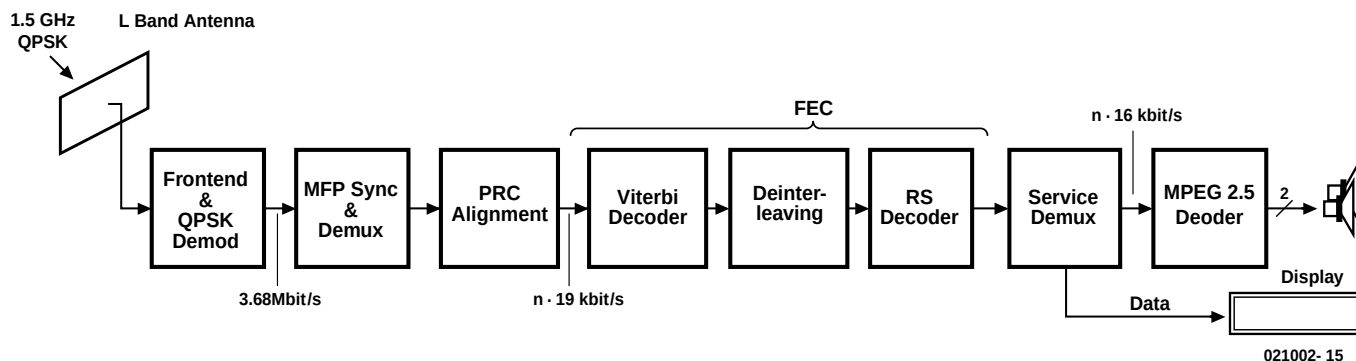


Figure 5. Block diagram of a WorldSpace receiver.

using four PRCs, a mono audio channel using two PRCs and a data channel using two PRCs. The stereo audio channel, the mono audio channel and the data channel thus form the three Service Components of the Broadcast Channel. These can be selected at the receiver at the press of a button.

Receiver

A WorldSpace receiver, as shown in **Figure 5**, includes a flat, or patch, antenna which is not highly directional. Its beamwidth is large, around 70 to eighty degrees both horizontally and vertically. The antenna therefore does not need to be particularly accurately aligned, as is the case with previous geostationary satellite systems.

The HF unit converts the 1.5 GHz signal down to a lower intermediate frequency. This front-end is in a double superheterodyne configuration: the 1.5 GHz signal is first converted down to a first intermediate frequency (IF) of, for example, 116 MHz. After bandpass filtering at this IF the signal passes to a further mixer, which converts the WorldSpace QPSK signal down to a very low second IF of 1.84 MHz. This is the lowpass filtered and converted to digital with an A/D converter. There follows a digital QPSK demodulator whose output is the 3.68 Mbit/s data stream. As described above, this data stream contains all the programmes in one beam in a time multiplex format. Subsequent processing is done in digital signal processors (DSPs) or application-specific ICs, known as the Starman WorldSpace Radio chipset. These originate from Micronas (Germany) and ST Microelectronics (France).

To assist in synchronisation there is a special word in the data stream called the Master Frame Preamble (MFP). Since this is fixed and unambiguous, it can also be used to resolve the phase ambiguity of the QPSK demodulator, which can lock on to the received signal with two different phase off-

sets. Once the demodulator is synchronised, the receiver can then accept the Time Slot Control Channel (TSCC) information, which forms part of the overall data stream. The extracted information gives the allocation of the PRCs to the various Broadcast Channels. The receiver stores this list in RAM to allow access at any time when selecting stations. This also allows quicker switching between stations.

In the Prime Rate Channel Alignment stage the PRCs that belong to the Broadcast Channel that has been selected are extracted from the overall data stream with the aid of the TSCC information. The microcontroller in the receiver tells the WorldSpace receiver chip which PRCs are required. By concatenating the selected PRCs a new data stream is constructed, which only contains the data for the chosen Broadcast Channel (BC). This now has a data rate of n times 19 kbit/s, where n is the number of PRCs used, from one to eight.

Next follow the three FEC stages required on the receiver side: the Viterbi decoder is the counterpart of the convolutional encoder and provides a first level of error correction. It tracks the transition from one symbol state (two bits) to the next and, knowing the coding algorithm used in the convolutional encoder, calculates the probability that the received transition could occur. If an alternative transition is seen to be more likely than the one received, the Viterbi decoder replaces the received one with the more likely one. These likelihood calculations are carried out continuously over a data window of 64 bits.

The deinterleaver distributes errors that affect consecutive bytes into separate positions spread out in time. The Reed-Solomon decoder that immediately follows can now detect and correct these burst errors.

The service demultiplexer takes the error-free data stream obtained and extracts the desired programme in the form of the n 16 kbit/s packets originally fed in, and sends them to the MPEG 2.5 decoder. At the same time the side channel data are extracted, and these are converted into a suitable form for display by the processor in the receiver. All WorldSpace receivers have a stereo headphone connection, and some also sport stereo loudspeakers. Very compact receivers must of course make do without stereo loudspeakers.

Because the error correction mechanisms behind WorldSpace radio are so cunning, reception is possible with a signal-to-noise ratio of only around 4 dB. The threshold for FM reception, as used for reception of analogue TV (from Astra etc.) lies at a signal-to-noise ratio of around 10 to 12 dB. Beneath this FM threshold the analogue TV picture starts to 'sparkle': brief flashes appear in the lines of the picture, which become more significant and hence more disturbing as the signal-to-noise ratio decreases.

Further, the receiver circuits in WorldSpace receivers are already designed with the nonlinearity of the travelling wave tube amplifier (TWTA) in the satellite transponder in mind. This nonlinearity can be compensated for, which improves still further the reception quality and the communication power budget.

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